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QUARTERLY PROGRESS REPORT ON CONTRACT NAS 8-2604 FOR MEASUREMENTS AND IMPROVEMENTS OF TWO HYDROGEN MASERS

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1. INTRODUCTION

The period herein covered is from December 1 1963 to February 29, 1964, and the work is mainly concerned with modifying the two NASA Atomic Hydrogen Masers, studies and prototype of a solid dielectric spherical cavity, and the establishment of a system to make short term measurements.

2. STATUS OF IMPROVEMENTS

a) Solid Dielectric Cavity

The blanks have been ground spherical by Engelhard and have been silvered. The resulting solid sphere of known dimensions allows an accurate measurement to be made of the dielectric constant of the quartz. By resonating it in several modes, a rough measure of the uniformity of the quartz over the volume of the sphere can be obtained.

The resonant frequencies are given by

$$\nu_{ns} = \frac{u_{ns}}{2\pi a\sqrt{\mu_o \epsilon_o k_e k_m}} \; ; \qquad \lambda_{ns} = \frac{2\pi a}{u_{ns}}$$

a is the radius of the cavity

u_{ns} are the roots of $j_n(k_1 a) = 0$ or $\left[k_1 a\, j_n(k_1 a)\right]' = 0$

where j_n are the spherical Bessel functions

$u_{11} = 4.50 \qquad u_{12} = 7.64$

$u_{21} = 5.8$

The lowest root of the second equation is given by

$u'_{11} = 2.75$

For the mode $u'_{11} = 2.75, \; k_e = 3.8268$

$u_{11} = 4.50, \; k_e = 3.8273$

Q was estimated at about 15000.

Using $\sqrt{k_e}$ to be 1.9563, the program for finding the inside boundary of the sphere to allow resonance at 1420,405 mc. was rerun, giving the inside radius to be 6.362 cm. for a given outside radius of 9.817 cm.

The cavity was ground to this size and resonated and found to be 700 kc. high. This fractional error of 0.5% will be removed by means of a metallic tuning plunger.

b) NASA Masers

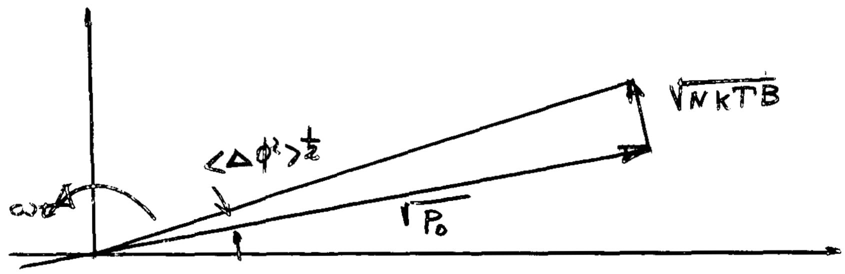
No. 1 NASA has been refitted with new pump elements from Varian. Both masers are being fitted with improved thermal control electronics. Thermal sensing will be done at four places instead of the usual three, and a monitoring point is also provided. The circuitry is complete for both masers and the modification of the oven heater is underway on No. 2 NASA maser. This device will also be refitted with new pump elements.

3. SHORT TERM STABILITY

The effect of system noise on the output of a hydrogen maser is very important when the measuring time intervals become short. This analysis describes the problem using a noise power analogy. The receiver system having noise figure N causes an r.m.s. phase fluctuation $<\Delta\phi^2>^{\frac{1}{2}} = \sqrt{\frac{NkTB}{P_o}}$

which can be visualized as a noise power vector in quadrature with the rotating signal vector.

$$\frac{<\Delta f^2>^{\frac{1}{2}}}{f} = \frac{1}{2\pi}\sqrt{\frac{NkTB}{Pt^2_{obs}}} \qquad (1)$$



The maser r.m.s. frequency fluctuation can be described in terms of a phase fluctuation obtained from

$$\frac{<\Delta f^2>^{\frac{1}{2}}}{f} = \frac{0.113}{Q_\ell}\sqrt{\frac{kT}{P_b t_{obs}}} \qquad (2)$$

where P_b is the power delivered to the cavity by the beam. The amount of power coupled out is given by $\frac{Q \text{ cavity, loaded}}{Q \text{ external}} P_b$.

$$<\Delta f^2>^{\frac{1}{2}} = \frac{0.113}{\pi\,\tau_{rad}}\sqrt{\frac{kTQ_e}{P_b tQ_c}}$$

$$<\Delta\phi^2>^{\frac{1}{2}} = 2\pi<\Delta f^2>^{\frac{1}{2}} t = \frac{2 \times 0.113}{\sqrt{\frac{kTt}{P_b\,\tau^2_{rad}}\,\frac{Q_e}{Q_c}}}$$

The sum of the two phase noises is obtained by adding the mean square components.

$$<\Delta\phi^2>^{\frac{1}{2}} = \left[(2 \times 0.113)^2\,\frac{FkTt}{P_b\,\tau^2}\,\frac{Q_{ext}}{Q_{cavity}} + \frac{NkTB}{P}\right]^{\frac{1}{2}} \tag{3}$$

where F is a measure of the excess maser phase fluctuation.

$$\Delta F = \frac{<\Delta f^2>^{\frac{1}{2}}}{f} = \frac{1}{2\pi f}\sqrt{\frac{kT}{P}\,\frac{Q_e}{Q_c}\,\frac{1}{t}}\left[0.226)^2\,\frac{Ft}{\tau^2} + NB\right]^{\frac{1}{2}}$$

If $\tau \doteq 0.3$ sec., then $\tau^2 = 0.1$ sec.

$F = 1;\quad N = 4$

$T = 300^0K$

$P = 10^{-12}$ watts $= 10^{-5}$ ergs/sec.

$\frac{Q_e}{Q_c} = 5.5;\quad B = 10$ cps.

then

$$\Delta f = \frac{1}{2\pi \times 1.4 \times 10^9}\sqrt{\frac{1.4 \times 10^{-16} \times 300 \times 5.5}{10^{-5}}}\left[\frac{(0.226)^2}{0.1}\,\frac{1}{t} + \frac{NB}{t^2}\right]^{\frac{1}{2}}$$

$$= 5.5 \times 10^{-14}\left[\frac{.31}{t} + \frac{4B}{t^2}\right]^{\frac{1}{2}}$$

For the range of times given below

$t = 10$ sec	$F = 3.7 \times 10^{-14}$
$= 1$ sec	$F = 3.5 \times 10^{-13}$
$= 0.1$ sec	$F = 3.5 \times 10^{-12}$

For t below 0.1 sec. the band pass of 10 cps is not sufficient and B must be made larger.

It must be borne in mind that equation (2) is accurate only for $t > \tau_{rad}$[1] and in the given examples τ_{rad} is taken as 0.3 sec. It is this departure from theory that is of interest in the measurements. The methods to differentiate the effect of receiver noise and that of the maser itself involve the use of cross-correlation techniques where the difference between the amplitude and phase components of noise from the maser will be measured. From this measurement the receiver noise, (amplitude and phase) can be obtained as well as the maser phase noise. As the time intervals become shorter, the difference in these components will become smaller compared to the increasing noise from the receiver which is isotropic in phase.

The correlator consists of a pair of receivers each consisting of an Electron Beam Parametric Amplifier, diode balanced mixer, and i.f. preamp and amplifier. Pump power for the parametric amplifier is obtained from a common source as is the local oscillator converter power. A second conversion, using a common local oscillator at 30 mc., brings both maser signals to a low frequency where they are amplified and fed to a device that produces a voltage proportional to the product of the two signals. The following are the measured parameters of the two individual systems.

Noise Figure N =	4 db
EBPA gain	18 db
Converter-preamp	27 db
I.F. amp.	60 db
Total gain up to second mixer	105 db

At the second mixers, where the frequency is converted from 30 mc/sec. down to a few tens of cycles per second, there will be some loss of power, perhaps as much as 7 db, as it is essential here to convert so as to preserve as carefully as possible the characteristics of the maser signal.

The output from the mixers is amplified and fed each to a channel of a function multiplier where the product of the two low frequency signals is made. When the phases of the two inputs are in quadrature, the output noise power from the multiplier is a measure of $\overline{\Delta\phi^2_T}$ where $\overline{\Delta\phi^2}_{total} = \overline{\Delta\phi^2}_{maser} + \overline{\Delta\phi^2}_{receiver}$.

According to the theory of the hydrogen maser the amplitude fluctuations are suppressed[1] and approach zero with increasing radiating power. It should be possible then, while the system is operating, to measure the receiver noise contributions alone when the signals are in phase and to measure the contribution of the phase (or frequency) fluctuations when the signals are in quadrature. By using filters at the inputs to the multiplier, various bandwidths can be chosen corresponding to different time intervals.

References

1. Daniel Kleppner, H. Mark Goldenberg, Norman F. Ramsey, "Theory of the Hydrogen Maser," Phys. Rev. 126, No. 2 (April 15, 1962).